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14. ABSTRACT This project identified the seasonal distribution and movements of fin whales in the Mediterranean Sea with satellite-monitored radio tags in relation to environmental parameters: sea surface temperature, chlorophyll concentration, current movement, primary production and prey abundance in collaboration with the laboratory of Dr. Christophe Guinet. By comparing these movements with the environmental parameters, a better understanding of fin whale ecology will be possible. The telemetry information will enable collaborators to study the coherence between the whales' movements, the observed oceanographic conditions and the simulated prey abundance/distribution model. The tracking data will also help determine the model's ability to accurately predict changes in fin whale distribution within the Mediterranean Sea during other seasons. Subsequent additional funding from MMS and the Joint Industry Program (JIP) allowed development and testing of a recoverable tag with GPS quality locations and highly detailed TDR records to evaluate underwater behavior of sperm whales. During this grant period ONR also supplied Argos support funds for <del>open whale studies in the Gulf of Mexico (MMS SWSS project, documenting of movements and distribution there) as well as</del>					
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# Final Technical Report to the Office of Naval Research

## Fin Whales in the Mediterranean Sea: Habitat Identification and Oceanographic Characterization

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### Abstract

This grant was a collaborative project with the laboratory of Dr. Christophe Guinet of the Centre d'Etudes Biologiques de Chizé (CEBC), France to identify the distribution and movements of fin whales in the Mediterranean Sea with satellite-monitored radio tags in relation to environmental parameters: sea surface temperature, chlorophyll concentration, current movement, primary production and prey abundance (Cotte et al, 2009). The tracked whales preferred habitats with predicted high densities of northern krill (*Meganyctiphanes norvegica*). The relationships were then used to develop a model by Dr. Guinet and colleagues, which would use these environmental parameters to predict fin whale distributions. Subsequent additional funding from MMS and the Joint Industry Programme (JIP) allowed development and testing of a recoverable tag with GPS quality locations and highly detailed TDR records to evaluate underwater behavior of sperm whales. During this grant period ONR also supplied Argos support funds for sperm whale studies in the Gulf of Mexico (MMS SWSS project), as well as blue whales and humpbacks in the Antarctic and Mexico (TOPP) (Lagerquist et al, 2008).

### Background

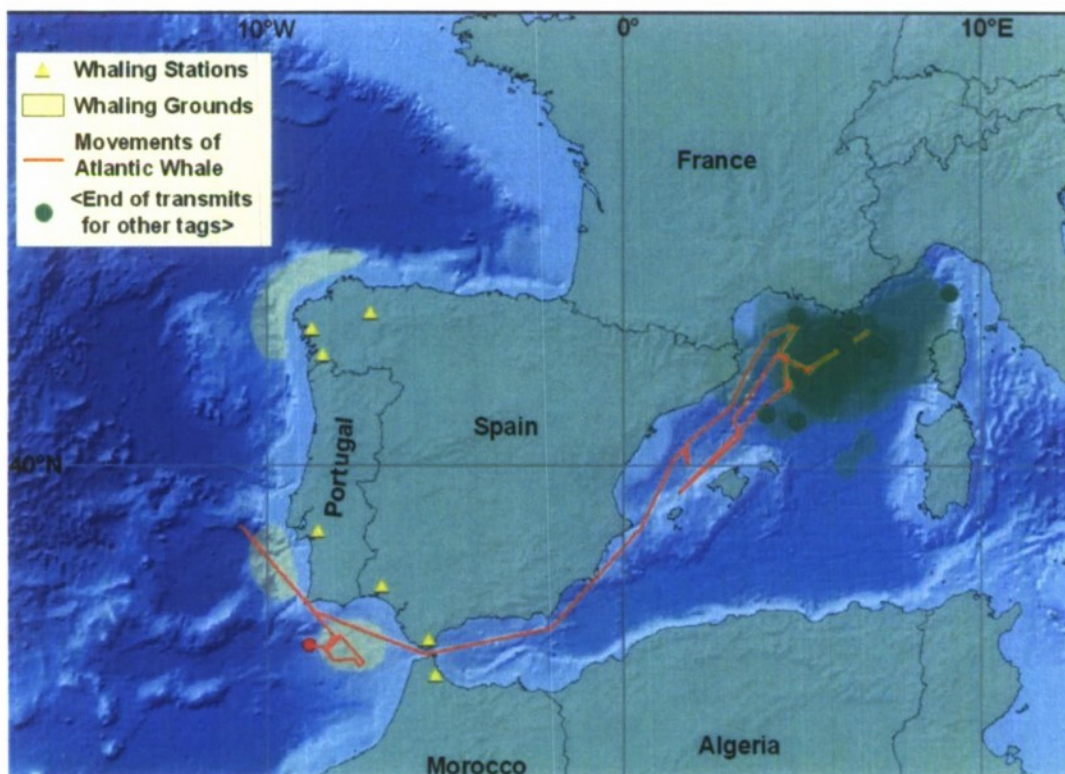
This project consisted originally of two parts: 1) tagging and monitoring of fin whales; and 2) examining the relationship between fin whale movements, environmental parameters and a model predicting fin whale distribution. Instead of a second field season in 2005 to tag again in the Mediterranean, the balance of funds were reallocated in combination with funds from MMS and JIP to demonstrate the feasibility of a new tag on sperm whales which provides GPS locations and Time-Depth Recorder (TDR) data. A no-cost extension was received in 2007 for the grant to end 9/30/08.

This project resulted in 5 publications being completed, 4 that are in preparation, 5 presentations at professional meetings, 5 workshop presentations, 1 JIP Program review, and 3 MMS presentations at information transfer meetings.



## Methods

During August 2003, 8 fin whales were equipped with Argos satellite tags. The semi-implantable tags (26 cm in length, 1.9 cm in diameter) consisted of a Telonies Argos ST-15 transmitter in a stainless steel tube, incorporating a flexible 12.5-cm whip-antenna, a flexible 4-cm saltwater switch (SWS), and two solid flanges (0.9–1.5 cm) to prevent inward migration and was partially coated with Gentamycins sulfate antibiotic in methacrylate (Eudragrits) for extended time-release of the antibiotic. The tag was applied to the back of the whale using an air-powered applicator from a 6-m rigid-hull inflatable boat at close range (1–3 m) within 2-m forward of the dorsal fin. To conserve batteries and extend tag operation, tags transmitted for only four 1-h periods daily for 90 days and then every 4<sup>th</sup> day thereafter. A saltwater switch and microprocessor were used to conserve battery power by limiting transmissions to times when the tag was out of the water and coinciding with optimal Argos satellite coverage which we modeled from satellite ephemeris data. We used screening criteria for Argos location classes 0–3 based on feasible swimming speeds (Mate et al., 1999). Details of the development of this tag and its current design were published as a grant objective (Mate et al, 2007).



## Examining whale/environmental relationships

The relationships between whale distribution/movements and environmental parameters (temperature, currents, chlorophyll/primary productivity, prey abundance) were examined in collaboration with CEBC. Environmental parameters developed by CEBC used both archival satellite data and dynamical/biogeochemical models (developed by Laboratoire d'Océanographie

Dynamique et de Climatologie, LODyC). The relationships between these parameters and fin whale movements was investigated using geostatistical methods.

#### **Publications cited that resulted from this work:**

- Cotte, C., C. Guinet, I. Taupeir-Letage, B. Mate, E. Petiau (2009). Scale dependent habitat use by a large free-ranging predator, the Mediterranean fin whale. *Deep Sea Research I* 56: 801-811.
- Mate, B.R. (2008). Technical instrumentation issues related to the design and execution of a controlled-exposure experiment for larger cetaceans to assess possible behavioural responses and potential impacts. *Bioacoustics*, Vol. 17, pp. 334-336. *Special issue: International Conference on the Effects of Noise on Aquatic Life, Nyborg, Denmark, August 13-17, 2007*
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- Benoit-Bird, K.J., Gilly, W.F, Au, W.W.L, & B. Mate (2008). Controlled and in situ target strengths of the jumbo squid *Doctidicus gigas* and identification of potential acoustic scattering sources. *Journal of the Acoustical Society of America*, 123: 1318-1328.

#### **Other citations:**

- Mate, B.R., B.A. Lagerquist, and J. Calambokidis. 1999. The movements of North Pacific blue whales off Southern California and their southern fall migration. *Marine Mammal Science*. 15(4):333-344.

#### **Abstracts presented at workshops and professional meetings:**

- Irvine, L., B.R. Mate. Habitat Characterization of Blue Whales (*Balaenoptera musculus*) off California. Oral presentation by L. Irvine at 17<sup>th</sup> SMM Biennial Meeting in Capetown, South Africa
- Irvine, L., B.R. Mate. Characterizing the dive habits of blue whales off California. Poster presentation by L. Irvine at pre-conference workshop entitled 'Gone today, here tomorrow?' Case studies of the elusive blue whale. 17<sup>th</sup> SMM Biennial Meeting in Capetown, South Africa
- Irvine, L., B.R. Mate. Diving Behavior of a Sperm Whale (*Physeter macrocephalus*) in the Western Gulf of Mexico. Poster presentation by L. Irvine at pre-conference workshop entitled Sperm Whales and Marine Ecosystems: Past, Present and Future. 17<sup>th</sup> SMM Biennial Meeting in Capetown, South Africa
- Mate, B. A GPS-tag to monitor whale dive and movement behavior for controlled exposure experiments. Poster presentation by B. Mate at International Conference on the Effects of Noise on Aquatic Life, Nyborg, Denmark, August 13-17, 2007
- Mate, B.R., L. Irvine. Seasonal movements and habitat characterization of blue whales in the eastern North Pacific. Oral presentation by B. Mate at pre-conference workshop entitled 'Gone today, here tomorrow?' Case studies of the elusive blue whale. 17<sup>th</sup> SMM Biennial Meeting in Capetown, South Africa
- Mate, B.R., R. Huckle-Gaete. The late summer feeding range, fall migration and winter habitat of Chilean blue whales. Oral presentation by B. Mate at pre-conference workshop entitled 'Gone today, here tomorrow?' Case studies of the elusive blue whale. 17<sup>th</sup> SMM Biennial Meeting in Capetown, South Africa
- Mate, B. R., J.G. Ortega-Ortiz, D. Engelhaupt. Annual movements and home range of sperm whales in the Gulf of Mexico. Oral presentation by B. Mate at pre-conference workshop on Sperm Whales and Marine Ecosystems: Past, Present and Future. 17<sup>th</sup> SMM Biennial Meeting in Capetown, South Africa



- Mate, B.R.** Comparative Biology of Rorquals from Electronic Tagging. Oral Presentation by B. Mate on TOPP Highlights of 2006-07. 17<sup>th</sup> SMM Biennial Meeting in Capetown, South Africa
- Mate, B.R., J. Urban.** A new satellite tag with GPS accuracy designed for a future controlled exposure experiment (CEE) for large cetaceans to assess possible behavioral responses and potential impacts. Oral presentation at SOMMEMA meeting by J. Urban. 17<sup>th</sup> SMM Biennial Meeting in Capetown, South Africa
- Ortega-Ortiz, J.G., B.R. Mate.** Foraging areas and migration timing of humpback whales from the western Antarctic Peninsula. Oral presentation by J. Ortega-Ortiz. 17<sup>th</sup> SMM Biennial Meeting in Capetown, South Africa
- Ortega-Ortiz, J.G., B.R. Mate.** Habitat preferences of sperm whales in the northern Gulf of Mexico. Oral presentation by J. Ortega-Ortiz at pre-conference workshop on Sperm Whales and Marine Ecosystems: Past, Present and Future. 17<sup>th</sup> SMM Biennial Meeting in Capetown, South Africa
- Ortega-Ortiz, J.G., D. Engelhaupt, B.R. Mate, R. Hoelzel.** Social structure and genetic relatedness of sperm whales in the Gulf of Mexico. Oral presentation by J. Ortega-Ortiz at pre-conference workshop entitled Sperm Whales and Marine Ecosystems: Past, Present and Future. 17<sup>th</sup> SMM Biennial Meeting in Capetown, South Africa
- Winsor, M., B.R. Mate.** Seismic survey activity and the proximity of satellite-tagged sperm whales in the Gulf of Mexico. Poster presentation by B. Mate at pre-conference workshop entitled Sperm Whales and Marine Ecosystems: Past, Present and Future. 17<sup>th</sup> SMM Biennial Meeting in Capetown, South Africa

## Tag development and progress

### Background

With ONR support, Oregon State University's Marine Mammal Institute pioneered the development and use of satellite-monitored radio tagging technology to track cetacean movements. Since 1986, we have successfully tracked seven species of large cetacean (blue, bowhead, fin, gray, humpback, right and sperm) and three species of small cetacean (Atlantic white-sided dolphin, bottlenose dolphin and pilot whale), with a maximum tracking period to date of 9.5 months. Our fin whale tracking took place in the Sea of Cortez, Mexico, in March 2001, as part of a collaboration with the University of California Santa Cruz and the autonomous University of Baja California Sur (Drs. Don Kroll and Jorge Urban). During this project, 11 fin whales were tagged and tracked for up to six months, resulting in 18,000 km of tracking. Recent improvements in our tagging technology have allowed for even longer term tracking ( $\geq$  one year). Antennae have been strengthened to allow for more "abuse," such as the rolling of calves over mothers' backs and contact between animals during mating. Long-dispersant antibiotics have been incorporated into the tag housings to reduce the potential for infection. In 2001, one year after applying tags with long-dispersant antibiotics, follow-up studies of North Atlantic right whales demonstrated that the average length of tag attachment was 11.5 months (nine resighted whales, eight of which still had the tags attached). Recent sightings in 2002 show many of these tags still attached and in good condition. In 2002, we switched from using a crossbow to using an air-powered applicator to deploy the tags. This more-powerful system has allowed for a more complete implantation of the subcutaneous tags (rather than only partial implantation achievable with the crossbow). In the first field season to incorporate this change (sperm whales in the Gulf of Mexico), 100% of the deployed tags reported data, which is a significant improvement over previous field seasons. As a result of these changes, tagging is now much more reliable and thus far, free from significant adverse effects to the animals.

Our tagging of fin whales in the Mediterranean has provided much of the first documentation of movements and distribution for this species there. By comparing these movements with the environmental parameters collected or modeled by CEBC/LODyC, a better understanding of fin whale ecology in the Mediterranean will be possible. The telemetry information will enable collaborators to study the coherence between the whales' movements, the observed oceanographic conditions and the simulated prey abundance/distribution model. The tracking data will also help determine the model's ability to accurately predict changes in fin whale distribution within the Mediterranean Sea during other seasons. We also found that one of 8 whales moved out into the North Atlantic during the winter, suggesting the Mediterranean is a mixed summer feeding aggregation of at least two fin whale stocks.

### **Development and testing of a GPS/TDR tag**

Newly designed GPS-Argos tags were tested on sperm whales and provided excellent locations and dive profiles in near real-time. These dive and movement data can assess natural variability and provide a basis for controlled exposure experiments (CEE) by detecting changes in whale behavior. Monitoring such changes can influence exposure levels during the course of an adaptive CEE to avoid over-exposing whales to sound and estimate the time to "recover" habits or habitats during post-CEE "observations."

Interpretation of potential foraging and energetic impacts rely upon sensor accuracy, resolution, and sampling rates design into the CEE. Monitoring the acoustic environment and assessing prey fields before, during, and after a CEE is highly desirable to interpret results and possible trophic consequences.

### **Methods**

During spring 2007, 13 sperm whales (Figure 1) were tagged with GPS-ARGOS tags using deployment and attachments similar to those already used for large whales (Mate et al., 2007).<sup>\*</sup> The tags were modified Wildlife Computers TDR-PAT-MK-10s with FastLoc<sup>TM</sup> GPS 21.5 mm dia. x 152.5 mm stem with a 101 mm dia. x 46 mm float at the antenna end). The sub-dermal "stem" (containing an Argos transmitter, FastLoc<sup>TM</sup> GPS receiver, TDR electronics, and batteries) was nearly identical in dimensions to the Argos location-only tags used during SWSS on sperm whales. Each tag fit into a spring-loaded stainless steel metal sleeve (25.5 mm dia. x 237.6 mm), which had a four-blade entry tip and backward facing pre-curved attachments, resulting in a larger overall diameter for the sub-dermal part of the tag than used before. The float was built by casting and machining a mixture of epoxy and glass micro-spheres around the GPS antenna to assure the tag would float when it was ejected from the sleeve with an upward "looking" position for the GPS antenna, an upright posture for the light-weight Argos antenna, and that a saltwater switch would go "dry" (break continuity with a grounding plate cast into the side of the float). A spring with 4.6 kg of compression force was used to break any "fouling growth" and eject the tag after 60d (using a corrodible wire release), so the tag could float to the surface and send its position. Thus, the tag could be recovered and the recorded TDR data (resolution: 1s and 0.5m) could be downloaded. Two other means of tag detachment were also possible. These were initiated when the batteries were calculated to be running out of power or if the tag did not change its depth (pressure readings) for 24 hours, suggesting that the tag had come off of the whale (and sunk to the bottom) or the whale had died.



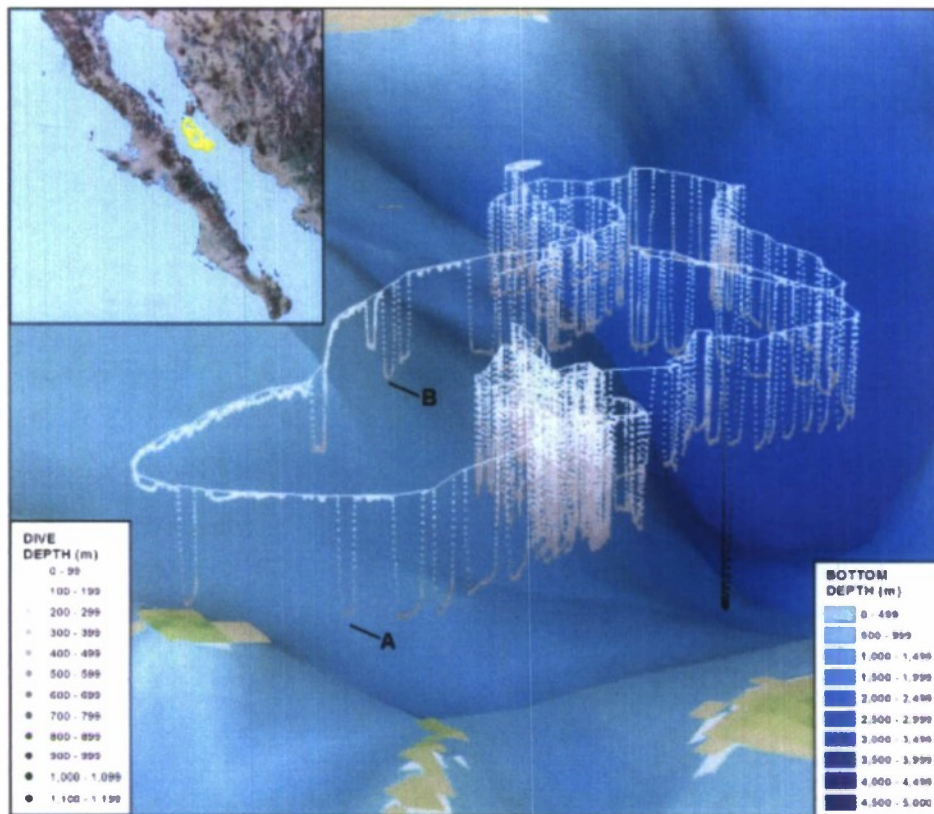


Figure 1. The detailed dive records of whale tag 5910 during a 9-day period in the Gulf of California during which most long dives were to 350 meters and the deepest dive was 1200 meters. The figure shows the bathymetric features including a period from "A" to "B" consisting of 44 hours of surface traveling at 3.7 km/hour over mostly shallow upper slope waters, during which only two exploratory dives exceeded 50 meters. The resumption of routine dives to 350 meters 4 hours after point "B" suggests the animal found sufficient prey densities to resume foraging activities.

Tags were programmed to transmit throughout the day and night (no duty cycle) during surfacings at a rate of at least one minute apart. A new GPS location was attempted immediately after dives lasting more than 10 minutes and achieving a depth of at least 10 m. A second GPS location was attempted at >5 minutes after each such dive to determine if the whale was moving at the surface during the surfacing interval when it was recovering oxygen debt to prepare for the next dive. If a GPS location was not successful on either, then an additional attempt could be made.

Tags sent three different types of Argos messages (location, dive, and utility). The location message consisted of GPS pseudo-ranges (alternately from the most recent GPS location or time-stamped recent historical GPS locations) which could be translated into a latitude and longitude location. Dive messages provided six dive summaries for rotating groups of recent dives including shape, duration, and maximum depth. The utility message monitored battery voltage, numbers of attempts to acquire GPS locations, and number of Argos transmissions. The utility message allowed us to monitor the efficiency of getting data through Argos and predicting if the

tags were preparing to release themselves before 60 days because they were using more power than expected. Location accuracy varied depending upon the number of satellites received by the tag's GPS receiver, which was reported as part of the location data stream message.

As the crew of the R/V Pacific Storm surveyed areas looking for whales or approached previously tagged whales, we often collected echo-sounder data to identify squid concentrations for future correlation with sperm whale movements. We were successful in this regard, but the results are not reported here (Benoit-Bird, et al., in press). GPS locations were recovered from Service Argos with an Iridium (satellite-linked) phone-modem via the Internet or by directly monitoring tag transmissions using shipboard receivers (one with an ADF) when we were within reception range. We used these data to relocate tagged whales and recover released tags. Data on GPS positions and detailed time-depth recordings (TDR) were downloaded from recovered tags using software supplied by Wildlife Computers. Argos and GPS positions were plotted with Arc View.

During the tagging field work, an experiment was conducted to determine the accuracy of the GPS locations in that region by attaching four recovered GPS tags and a GPS receiver to a life ring and then setting them afloat.

\*In addition to 13 GPS tags, ten location-only tags were also deployed and provided outstanding results. We have heard from all of these tags and the average duration of operation was 193 with a maximum of 442 d.

## Results

During the tag calibration experiment, the life ring drifted 900m south and 500m east. The GPS-acquired locations had a mean difference of within  $\pm 62$  m of the GPS receiver's reported position. Position accuracy is directly related to the number of satellites acquired by the GPS tag's receiver, which varied from four to ten. One tag had significantly higher error than the others, due in large part to a single outlier of 445m that occurred during a four satellite acquisition, which are the most error prone.

Data were received from all 13 tags after they were applied to whales, but the longest track was tag # 5910, which was tracked for nine days before it was released and recovered. During field operations, six tags came off whales prematurely due to broken corrodible wires, and all were recovered (three at night) using GPS locations from the tags. These recoveries demonstrated our ability to monitor tag-transmitted data from the ship in real-time and translate the data into extremely precise GPS locations.

The number of locations differed between the three types of locations we acquired. GPS locations relayed via Argos ( $n=256$ ) were more than twice as frequent as Argos locations ( $n=104$ ), but represented only 31% of the GPS locations downloaded from recovered tags ( $n=824$ ). GPS locations were considerably more accurate than Argos locations. Argos locations (all location classes) averaged 4.5 km from the GPS location, while the higher location classes ( $LC=0,1,2$ , or  $3$ ) were within 1.1 km. Such differences would make very large differences in noise exposure if they were used to estimate distance between whales and a source vessel during



a CEE. A small difference was detected between archived GPS locations and those received via Argos, which was attributable to the different algorithms used to translate pseudo-range data into locations by these two techniques. Naturally, tracks created from the more frequent and precise GPS locations revealed more detail than Argos locations and more confidence in the estimation of actual movements and ancillary relationships, such as water-depth data from charted values. (The charts in this area do not accurately portray island locations and water depths.)

Downloaded TDR records provide added detail beyond the summary dive records received via Argos in real-time. Zigzag vertical patterns during the deepest portion of the dive likely reflect foraging lunges to capture Humboldt squids, the subject of a large local year-round fishery. Some tagged whales demonstrated consistent dive depths over multiple days (and nights), while others were more variable. Correlating locations with specific dive- and surface-oriented activities provided insight into resting, foraging, and traveling. As an example, the dive record for the period "A-B" in Figure 7 reveal only two dives >50 m in a 12 h period. If this record were considered alone, a plausible interpretation might be that the whale was "surface resting". However, using the 23 archived GPS locations during this period, the whale clearly moved at 3.7 km/hr over a 44 km distance, including over a shelf where water was shallower than previous routine dive depths. The two deep dives during the 12 h period thus suggest "exploratory dives," probably looking (unsuccessfully) for food until location "B" where frequent deep dives suggest resumed feeding.

We examined the diving record of tag #5910 to evaluate what percentage of surfacings resulted in GPS attempts, GPS positions, and Argos positions. This tag sent 3701 transmissions, of which 62 were received by Argos, and yielded 48 location estimates. Of 335 qualifying dives, 534 GPS position attempts were made: 312 immediately upon surfacing and 222 after more than 5 minutes of the initial surfacing. There were 439 successful GPS locations acquired (82.1% of attempts): 237 (76% of attempts) immediately after surfacing (174 were successful on the first attempt and 63 on a re-try) and 201 "2nd" locations (90.5% of attempts) during the surfacing interval (183 were successful on the first attempt and 18 on a re-try). Thus, we acquired immediate locations on 71% of all qualifying dives and 60% of all surfacing intervals. One received location was not associated with a dive event. Of 96 failed GPS attempts (17.9% of total), 79 were aborted due to the tag not remaining dry for a long enough period and 17 for not having acquired enough satellites (>3). All values reported here are close to the mean for all six recovered tags.

## Discussion

The whales in the Gulf of California were larger, fatter, and "tougher" to penetrate than sperm whales we tagged in the Gulf of Mexico. This was especially true of large males, so part of our difficulty in achieving complete tag deployments was empirically determining an appropriate air pressure for the applicator to achieve complete tag penetration. While baleen whale tags required 80 psi, small and female sperm whales required 100 psi and tags on large males did not fully deploy sometimes even with 125 psi.

Six GPS tags were deployed on the first day of tagging and data were received from all six. Four tags were applied during the second day of tagging before it was realized that tags were coming off prematurely. As a result, the last three tags we applied were permanently attached to their

sleeve, so the corrodible link was disabled. Only one of these three tags was fully deployed in terms of tag depth, and it transmitted data for 40 days. We observed one tag still attached to a whale but not operating, so at least one unexplained malfunction occurred. Two of the recovered tags had been damaged by the stretching of the corrodible wire. This allowed water penetration, but did not prevent their continued transmission. We are confident that the breakage of the corrodible link can be solved to result in a reliable design for longer-term attachment. We observed several whales with the attachment sleeve still attached after the floatable tag had ejected. We have supplied Mexican research colleagues with a photo identification catalogue of tagged whales and anticipate receiving follow-up reports about the duration of the sleeve attachments and healing (tag effects). We hope to go back to this area for additional research and follow-up on possible tag effects.

An ADF was used to locate the tags at close range by plotting the tag's reported GPS position in relation to the vessel's GPS coordinates. The receiver we used for the ADF had a disappointing range of 1.6 km, limited by a simple antenna and poor receiver sensitivity. An improved antenna, added antenna height, and a receiver with much greater sensitivity could improve the reception range to line of sight (6—10 miles at 20' of antenna height in reasonable seas).

Detailed dive data from these tags are the first of their kind (for any whale species) for such long durations, and offer examples of how animal dives (even in the same area) can vary. With modification of the attachment release mechanism, the GPS tag makes a two month-long CEE possible. Such an experiment would provide pre- and post-exposure control periods to evaluate site tenacity, displacement, and changes in dive habits, as well as multiple exposures of the same tagged whales at different noise levels to develop strong statistical confidence in results that might be used for regulation and mitigation measures. If whales are displaced or significantly alter their dive habits during a CEE, an evaluation of their return to pre-CEE sites and habits can help evaluate the duration of possible effects, providing insights into habituation and "recovery." By passing calibrated acoustic buoys at the same distances as tagged whales, this percentage is sufficient to reliably predict whale locations for the estimation of sound exposure when animals are not moving rapidly over large areas. The recovery of tags after a CEE will provide much finer scale resolution than Argos locations, allowing a more accurate estimation of noise exposure levels to better interpret results.

To properly position an approaching source vessel during a CEE, additional means of recovering GPS location and dive data from tagged whales in real time may be needed. This could be achieved by using an aircraft or a secondary (smaller) vessel equipped with an uplink receiver when satellites are not overhead.



## References

- Benoit-Bird, K.J., Gilly, W.F, Au, W.W.L, & B. Mate (2008). Controlled and in situ target strengths of the jumbo squid *Docidicus gigas* and identification of potential acoustic scattering sources. *Journal of the Acoustical Society of America*, 123: 1318-1328.
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- Mate, B., R. Meseear, and B. Lagerquist. 2007. The evolution of satellite-monitored radio tags for large whales: One laboratory's experience. *Deep-Sea Research II*. 54:224-247.

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*After this contract had ended, an additional presentation of further analyses was presented (attached).*

**Abstract: Biologging III meeting, Asilomar, Sept. 1-5, 2008**

**AN ARGOS-GPS-TDR TAG MONITORS PRECISE MOVEMENTS AND DIVE BEHAVIOR TO MAKE PROLONGED LARGE WHALE CONTROLLED EXPOSURE EXPERIMENTS POSSIBLE**

BRUCE R. MATE

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**Abstract**

Detailed dive and movement information is important in order to plan, execute, and interpret a seismic-source controlled-exposure experiment (CEE) for large whales. Obtaining extended information from instrumented whales has been difficult from previous tag type, which have either been too short in attachment or have lacked adequate resolution. With JIP funding, Wildlife Computers TDR-PAT-MK-10 tags were modified to incorporate a Fastloc GPS receiver for more accurate locations than Argos. The GPS locations and time-depth records were designed to evaluate behavioral responses to sound exposure for 60 days (before, during and after a 3-week long future CEE).

During spring 2007, 13 sperm whales in the Gulf of California were equipped with GPS/TDR tags, using deployment methods already successful for large whales (Mate et al., 2007). The tags were programmed to detach after 60d, float to the surface, and relay updated GPS locations to facilitate their recovery. While still attached, the tags sent GPS locations (avg. acquisition time = 1.2s) and dive summary data (shape, duration and depth) via Argos after dives >10min and >10m. The field team obtained GPS locations from tagged whales as Argos data via sat-phone linked Internet and also directly from tag transmissions using a vessel-based uplink receiver and data from the vessel's conventional GPS receiver. Whale locations were displayed on a laptop PC in an ADF-like manner showing the whale's location relative to the vessel to facilitate relocating tagged whales or recover released tags. During the field season, six tags were recovered this way, including three at night, demonstrating the precision of the integrated system.

Once retrieved, high resolution TDR and detailed GPS data provided insights into both dive- and surface-oriented behaviors, including resting, foraging, and traveling. GPS data revealed more detailed tracks than ARGOS because of more frequent (65% of all locations after dives more than 10 min) and precise locations (avg. = 62m). Dive records with 1s and 2m resolution revealed lunges during the deepest portion of the dive, likely reflecting foraging attempts on Humboldt squids, a local year-round fishery. Some whales demonstrated amazingly consistent deep dive depths, while most were much more variable. There was good general agreement in the periods of active diving for whales which stayed close together over extended periods (close association), although they did not exhibit routine dive synchrony in either timing or dive depths.